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Main Menu | Search Form | Posting Counts | Show S Numbers | Edit S Numbers | Preferences | Cases

Search Results -

Term	Documents
AUTOMATED	174060
AUTOMATEDS	0
CONTROL	4576922
CONTROLS	980917
(1 AND (AUTOMATED SAME CONTROL)).USPT,JPAB,EPAB,DWPI.	9
(L1 AND (AUTOMATED SAME CONTROL)).USPT,JPAB,EPAB,DWPI.	9

Database:
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Derwent World Patents Index
IBM Technical Disclosure Bulletins

Search: L2

Refine Search

Recall Text | Clear

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DATE: Wednesday, November 26, 2003 Printable Copy Create Case

Set Name side by side	Query	Hit Count	Set Name result set
	DB=USPT,JPAB,EPAB,DWPI; PLUR=YES; OP=ADJ		
L2	L1 AND (automated SAME control)	9	L2
L1	(injection ADJ molding) AND (injection ADJ (stroke OR velocity))	639	L1

END OF SEARCH HISTORY

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Search Results - Record(s) 1 through 9 of 9 returned.

☐ 1. Document ID: US 6004095 A

L2: Entry 1 of 9 File: USPT Dec 21, 1999

US-PAT-NO: 6004095
DOCUMENT-IDENTIFIER: US 6004095 A

TITLE: Reduction of turbomachinery noise

DATE-ISSUED: December 21, 1999

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Waitz; Ian A.	South Natick	MA		
Brookfield; John M.	Somerville	MA		
Sell; Julian	Ann Arbor	MI		
Hayden; Belva J.	McLean	VA		
Ingard; K. Uno	Kittery Point	ME		

US-CL-CURRENT: 415/119; 415/115, 415/914, 416/97R

ABSTRACT:

In the invention, propagating broad band and tonal acoustic components of noise characteristic of interaction of a turbomachine blade wake, produced by a turbomachine blade as the blade rotates, with a turbomachine component downstream of the rotating blade, are reduced. This is accomplished by injection of fluid into the blade wake through a port in the rotor blade. The mass flow rate of the fluid injected into the blade wake is selected to reduce the momentum deficit of the wake to correspondingly increase the time-mean velocity of the wake and decrease the turbulent velocity fluctuations of the wake. With this fluid injection, reduction of both propagating broad band and tonal acoustic components of noise produced by interaction of the blade wake with a turbomachine component downstream of the rotating blade is achieved. In a further noise reduction technique, boundary layer fluid is suctioned into the turbomachine blade through a suction port on the side of the blade that is characterized as the relatively low-pressure blade side. As with the fluid injection technique, the mass flow rate of the fluid suctioned into the blade is here selected to reduce the momentum deficit of the wake to correspondingly increase the time-mean velocity of the wake and decrease the turbulent velocity fluctuations of the wake; reduction of both propagating broad band and tonal acoustic components of noise produced by interaction of the blade wake with a turbomachine component downstream of the rotating blade is achieved with this suction technique. Blowing and suction techniques are also provided in the invention for reducing noise associated with the wake produced by fluid flow around a stationary blade upstream of a rotating turbomachine.

49 Claims, 36 Drawing figures
Exemplary Claim Number: 1
Number of Drawing Sheets: 23

☐ 2. Document ID: US 5997778 A

L2: Entry 2 of 9 File: USPT Dec 7, 1999

US-PAT-NO: 5997778
DOCUMENT-IDENTIFIER: US 5997778 A

TITLE: Auto-tuned, adaptive process controlled, injection molding machine

DATE-ISSUED: December 7, 1999

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Bulgrin; Thomas C.	Columbia Station	OH		

US-CL-CURRENT: 264/40.1; 264/328.1, 264/40.7, 425/145, 700/200

ABSTRACT:

An injection molding machine uses a summed, multi-term control law to control ram velocity during the injection stroke of a molding cycle to emulate a user set velocity profile. An automatic calibration method sets no load ram speeds to duplicate user set ram speeds. Finite impulse response filters produce open loop, no load control signals at advanced positions on the velocity profile to account for lag in system response. An adaptive, error term indicative of load disturbance, observed from a preceding cycle is added at the advanced travel position predicted by the finite impulse response filter to produce a predictive open loop, load compensated control signal. Finally, an auto tuned PID controller develops a real time, feedback load disturbance signal summed with the open loop control signal to produce a drive signal for the machine's proportioning valve.

35 Claims, 10 Drawing figures
Exemplary Claim Number: 1
Number of Drawing Sheets: 10

☐ 3. Document ID: US 5112213 A

L2: Entry 3 of 9 File: USPT May 12, 1992

US-PAT-NO: 5112213
DOCUMENT-IDENTIFIER: US 5112213 A

TITLE: Driven ring-type non-return valve for injection molding

DATE-ISSUED: May 12, 1992

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Oas; David C.	Westlake	OH		

US-CL-CURRENT: 425/562; 366/79, 425/563, 425/587

ABSTRACT:

A non-return valve for an injection molding machine is provided which includes a

conventional tip member threaded into the end of a plasticating screw and carrying therewith an annular valve seat member. An annular check ring receives the tip member. Tang protuberances axially extend from the check ring to rotably engage the retainer end of the tip member. This causes the check ring to couple with the tip member during screw rotation to minimize valve wear while permitting the check ring to axially move relative to the tip member for effecting valve closure by pressure differentials in the normal manner. A ramp surface is provided on the tang protuberances which engages a drive surface on the retainer end of the tip/stud member upon reverse rotation of the screw through a predetermined rotational angle or for a set time to positively close the valve prior to injection.

11 Claims, 13 Drawing figures
Exemplary Claim Number: 1
Number of Drawing Sheets: 4

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments   KWIC | Draw. Desc | Image

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☐ 4. Document ID: US 4908169 A

L2: Entry 4 of 9   File: USPT   Mar 13, 1990

US-PAT-NO: 4908169
DOCUMENT-IDENTIFIER: US 4908169 A

TITLE: Method for plasticating using reciprocating-screw having a melt channel and solids channels

DATE-ISSUED: March 13, 1990

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Galic; George J.	Columbia Heights	MN	55421	
Maus; Steven M.	Osseo	MN	55369	

US-CL-CURRENT: 264/410; 264/328.14, 264/349, 264/40.6, 366/145, 366/146, 366/90, 425/143, 425/208, 425/587

ABSTRACT:

Method for improved melt quality of thermoplastics processed in reciprocating-screw molding, especially optical injection molding processes. In a reciprocating-screw injection-drive unit (4) is a barrel (53) and screw (15). Screw (15) is double flighted throughout its melting or transition zone (2), to form melt channel (48) and solids channel (50) separated by melt-filtering flight element (47), and kept in fluid communication by melt-transfer apertures (47 or 55 or 56) or substantially nonvertical ramped barrier flight geometry (not shown). The largest energy input for melting is directly provided by thermal conductivity, via electrical resistance heating elements. The primary source of such heat is by such elements (35) mounted internal to screw (15), and operating in an open loop control with respect to melt temperature sensor (22); secondary heat sources are elements (12, 13, 14, 29) mounted external to barrel (53) and nozzle (33) and operating in a closed loop manner with respect to barrel temperature sensing device (17, 19, 21, 30) and/or melt temperature sensor (22). By screw geometry designed to keep the solids bed (24) continuously under compression and by suitable numbers and sizes of apertures (47 or 55 or 56), melt films are continuously transferred away from the screw's and barrel's heated surfaces as fast as they are formed, thereby minimizing residence times at peak temperature and maintaining maximal heat transfer rates.

20 Claims, 14 Drawing figures
Exemplary Claim Number: 1

Number of Drawing Sheets: 6

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments   KWIC | Draw Desc | Image

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☐ 5. Document ID: US 4311446 A

L2: Entry 5 of 9   File: USPT   Jan 19, 1982

US-PAT-NO: 4311446
DOCUMENT-IDENTIFIER: US 4311446 A

TITLE: Injection molding machine controls

DATE-ISSUED: January 19, 1982

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Hold; Peter	Milford	CT		
Notte; Angelo J.	Milford	CT		
Rizzi; Marc A.	Orange	CT		

US-CL-CURRENT: 425/144; 425/145

ABSTRACT:

Method and apparatus for controlling the parameters of injection molding processes in a machine having a barrel with a plasticating chamber and a screw, rotatably and slidably disposed in said chamber, hopper means adjacent one end of said chamber communicating therewith and nozzle means disposed in the other end of said chamber communicating with a mold. Control of the injection molding process is achieved through an event recognition philosophy by sensing screw position, screw injection velocity, melt temperature, comparing the values at certain instances during the work cycle with known or desired values and using these values, changes of values and differences of values to monitor and initiate changes in the process parameters.

4 Claims, 7 Drawing figures
Exemplary Claim Number: 1
Number of Drawing Sheets: 5

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments   KWIC | Draw Desc | Image

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☐ 6. Document ID: US 4293229 A

L2: Entry 6 of 9   File: USPT   Oct 6, 1981

US-PAT-NO: 4293229
DOCUMENT-IDENTIFIER: US 4293229 A
**** See image for Certificate of Correction ****

TITLE: Hydraulic controls for injection unit of injection molding machine

DATE-ISSUED: October 6, 1981

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Hehl; Karl	7298 Lossburg 1			DE

US-CL-CURRENT: 366/78; 366/333, 60/445

ABSTRACT:

Hydraulic controls for the injection unit of an injection molding machine of the type which has tandem supporting bridges riding on two guide rods and hydraulic cylinder assemblies surrounding the rods, the cylinder assemblies in the rear supporting bridge which control the movements of the plastification screw being convertible from single-acting cylinders to double-acting cylinders with a differential piston, for the selective connection to a first hydraulic control system which has presettable proportional-response control valves for the adjustment of the pressure and flow rate of the hydraulic fluid, or to a second hydraulic control system which provides a continuous electronic control input to a servo-valve, adjusted by an electronic feedback loop with pressure transducers. The conversion involves the exchange of a piston and a cylinder cover in the two cylinder assemblies of the rear supporting bridge.

7 Claims, 6 Drawing figures
Exemplary Claim Number: 1
Number of Drawing Sheets: 4

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments | KWIC | Drawi Desc | Image

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☐ 7. Document ID: US 4094940 A

L2: Entry 7 of 9 File: USPT Jun 13, 1978

US-PAT-NO: 4094940
DOCUMENT-IDENTIFIER: US 4094940 A

TITLE: Injection molding machine controls

DATE-ISSUED: June 13, 1978

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Hold; Peter	Milford	CT		

US-CL-CURRENT: 264/40.6; 264/328.13, 700/202

ABSTRACT:

Method for controlling the parameters of injection molding processes in a machine having a barrel with a plasticating chamber and a screw, rotatably and slidably disposed in said chamber, hopper means adjacent one end of said chamber communicating therewith and nozzle means disposed in the other end of said chamber communicating with a mold. Control of the injection molding process is achieved through an event recognition philosophy by sensing screw position, screw injection velocity, melt temperature, comparing the values at certain instances during the work cycle with known or desired values and using these values, changes of values and differences of values to monitor and initiate changes in the process parameters.

3 Claims, 7 Drawing figures
Exemplary Claim Number: 1
Number of Drawing Sheets: 5

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments | KWIC | Drawi Desc | Image

☐ 8. Document ID: US 3937776 A

L2: Entry 8 of 9 File: USPT Feb 10, 1976

US-PAT-NO: 3937776
DOCUMENT-IDENTIFIER: US 3937776 A
**** See image for Certificate of Correction ****

TITLE: Method for controlling injection molding machines

DATE-ISSUED: February 10, 1976

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Hold; Peter	Milford	CT		
Notte; Angelo J.	Milford	CT		
Rizzi; Marc A.	Orange	CT		

US-CL-CURRENT: 264/40.4; 264/328.13, 264/40.5, 264/40.6, 264/40.7

ABSTRACT:

Method for controlling the parameters of injection molding processes in a machine having a barrel with a plasticating chamber and a screw, rotatably and slidably disposed in said chamber, hopper means adjacent one end of said chamber communicating therewith and nozzle means disposed in the other end of said chamber communicating with a mold. Control of the injection molding process is achieved through an event recognition philosophy by sensing screw position, screw injection velocity, melt temperature, comparing the values at certain instances during the work cycle with known or desired values and using these values, changes of values and differences of values to monitor and initiate changes in the process parameters.

8 Claims, 7 Drawing figures
Exemplary Claim Number: 1
Number of Drawing Sheets: 5

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments KWIC | Draw Desc | Image

☐ 9. Document ID: US 3870445 A

L2: Entry 9 of 9 File: USPT Mar 11, 1975

US-PAT-NO: 3870445
DOCUMENT-IDENTIFIER: US 3870445 A
**** See image for Certificate of Correction ****

TITLE: INJECTION MOLDING MACHINE CONTROLS

DATE-ISSUED: March 11, 1975

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Hold; Peter	Milford	CT		
Notte; Angelo J.	Milford	CT		
Rizzi; Marc A.	Orange	CT		

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L2: Entry 5 of 9 File: USPT Jan 19, 1982

DOCUMENT-IDENTIFIER: US 4311446 A
TITLE: Injection molding machine controls

Abstract Text (1):
Method and apparatus for controlling the parameters of injection molding processes in a machine having a barrel with a plasticating chamber and a screw, rotatably and slidably disposed in said chamber, hopper means adjacent one end of said chamber communicating therewith and nozzle means disposed in the other end of said chamber communicating with a mold. Control of the injection molding process is achieved through an event recognition philosophy by sensing screw position, screw injection velocity, melt temperature, comparing the values at certain instances during the work cycle with known or desired values and using these values, changes of values and differences of values to monitor and initiate changes in the process parameters.

Brief Summary Text (2):
This invention relates to advanced control systems for injection molding such as supplied by the Farrel Company, Division of USMCorporation, Ansonia, Conn. These controls may be said to be extensions of conventional control system concepts. In this regard, conventionally, a number of direct process variables such as melt temperature and shot volume are adjusted indirectly by manipulating or adjusting the various direct machine controls such as position limit switches, speed regulators, and timing devices which may be directly mounted upon the machine to effect these variables. Other direct process variables such as shot holding time and in mold time are conventionally controlled by timer without being controlled positively in direct relation to specific events within the injection process. In the advanced control system subsequently described, conventional machine sensors and actuators affecting the various events in the total process have been repositioned, replaced and supplemented, and the machine controls have been sequentially readjusted and made interresponsive to provide an overall control of the injection molding procedure not previously available.

Brief Summary Text (3):
Among the overall objectives of the control system, the advance control system is to control certain key process variables individually, or directly, by individually sensing the process parameters and generating appropriate feed-back signals, and then using these signals to initiate or perform the specific control task for adjustment of the process. This, to a large extent, enables the usual machine process control decisions to be taken out of the hands of manual operators and provides a system which produces an acceptable product under semi-automated and varied operating conditions. The advanced control system contemplated herein may be broken down into several subsystems performing individual or localized process control functions; and among these are melt temperature control, shot volume control and various monitoring of "remote" control process variables.

Brief Summary Text (4):
The present invention relates in general to method and apparatus for controlling the plasticating of polymeric materials in injection molding processes. More specifically, this invention relates to (1) control of the heat energy supplied to or generated within the plasticating apparatus for melting and plasticating the material; (2) control of the quantity of plastic material subsequently injected into a mold associated with the machine; (3) sequential and quantitive control of the various pressures exerted on the plastic material during the injection process; and

(4) the flexibility to provide coordinated adjustment of all of the above in response to product evaluation signals when direct input of these values is available.

Brief Summary Text (6):
It has been recognized that the plastic materials used in the injection molding processes today often require that the melt temperature be accurately controlled in order to carry out the injection molding process effectively. If the plastic material is either below or above the required temperatures the material may be incompletely plasticated or it may become discolored or otherwise deteriorated before or during injection molding procedure.

Brief Summary Text (8):
No controls existed prior to our invention to adjust and insure proper temperature of the melted, plasticated mass and to insure effective injection by a straightforward, sequential event-related approach. In many of the conventional plasticating and injection molding apparatus, the actual temperature of the mass injected is not measured or coordinatedly controlled during the continuing, repeated steps of the injection molding process. Much of the effort of control has been directed to a trial and error approach, finding acceptable values and then running a machine with these set values, with no provision for feed-back signals to check the set values. Specifically, these methods often only employ nominal temperature correction subsequent to the molding process consistent with visual observations of ineffective molding such as the aforementioned color changes or other material deterioration or the improper filling of a mold or other visible indications of unmixed or poorly mixed injection materials.

Brief Summary Text (10):
Resolution of the shot to shot problems involved in control of the melt temperature, however, do not individually provide the necessary speed of production in control over the production process to bring about the economy, efficiency and quality of production necessary for automated, high speed production. That aspect of the system should be coupled to responsive event control of shot volume and a continuing monitor/control of the injection stroke of the plasticating screw.

Brief Summary Text (11):
Conventional methods of controlling the volume of material injected into a mold by an injection molding machine include various timing means, position limit switches and position control switches influencing the screw backstroke to control the amount of polymeric material collected within the mixing chamber and then injected into the mold. It should be recognized that these conventional controls systems utilize input commands which are not indicative of the particular process parameters, or true events of the process. These conventional controls merely initiate step-by-step functions set by trial and error. By such conventional control systems the various process pressures and flow rates developed within the system are controlled by manual adjustment of relief valves and flow control valves, timing devices and the like.

Brief Summary Text (13):
While these conventional machines have been somewhat satisfactory for operation on relatively low volume basis, the control methods employed therein are totally unsatisfactory for a high-speed, fully automated molding machine. More particularly, the conventional control approaches would be totally unsatisfactory for a computer controlled machine including sensors capable of detecting the imperfections in its molding processes and products, and making appropriate corrections by adjustments in the particular process parameters which make up the molding process.

Brief Summary Text (14):
The present invention, then, relates to method and apparatus for incrementally adjusting the temperature generated within one charge of the injection molding process, by coordinatedly controlling the speed of rotation of the screw, the back pressure of the screw and the barrel temperature of the plasticating chamber. In coordination with this, the invention includes method and apparatus for continually controlling the volume of the shot injected into the mold in the machine, and in addition the coordinated control of the sequential injection stroke of the screw

according to the pressure and velocity patterns of the melt and screw during the injection process.

Drawing Description Text (2):
FIG. 1 is a diagrammatic presentation of the injection molding machine and control therefor, in accordance with the invention;

Drawing Description Text (4):
FIG. 2a is a graphic representation of position, velocity and pressure pattern with respect to time during injection molding;

Detailed Description Text (2):
Method and apparatus for controlling the parameters of injection molding processes in a machine having a barrel with a plasticating chamber and a screw, rotatably and slidably disposed in said chamber, hopper means adjacent one end of said chamber communicating therewith and nozzle means disposed in the other end of said chamber communicating with a mold. The general work cycle of such machine includes introducing polymeric material into said chamber through said hopper, rotating said screw to plasticate said material during which the screw is retracted in said chamber, and injecting the plasticated material into the mold through the nozzle by a forward or injection thrust of the screw. Control of the injection molding process is achieved through an event recognition philosophy by sensing screw position, screw injection velocity, melt temperature, comparing of values at certain instances during the work cycle with known or desired values and using these values, changes of values and differences of values to monitor and initiate changes in the process parameters.

Detailed Description Text (4):
The subsequent description relates to a new family of control systems for injection molding machines. As subsequently discloed, a family ultimately consists of three members. The basic control system (FBC), the process control system (FPC) and preferably the multivariable computer control system (FMC), all of which are closely related. By coupling the second member of the system to the first member and subsequently the third member to the group of the first two members, the resultant systems demonstrate increasing degrees of sophistication which exhibit an increasing independence from the human factor.

Detailed Description Text (5):
The basic control system which will subsequently be described, by and large follows a control strategy similar to today's conventional injection molding machine control systems. It will be pointed out however that this conventional strategy is uniquely implemented by virtue of the new understanding of injection molding process control and the particular combinations of sensors and systems employed to direct the various modes of the injection molding process. The basic control system is particularly adapted to perform with the process conrol (FPC).

Detailed Description Text (6):
The overall objective of the process control, (FPC), is to maintain the quality of the molded part independent of disturbances and variations in the injection molding environment once the primary operator has established the various control settings for the modes of injection molding. This objective is achieved by either introducing changes into the process variables which have deviated from the original set values or by warning the basic operator giving an indication of the process parameter which has deviated from the original setting, and which previously resulted in an acceptably molded part.

Detailed Description Text (7):
The process control (FPC) as subsequently described includes five subsystems which may be variously selected and combined to provide certain injection molding mode controls. Specific description of the subsystems and their interrelation with each other and the process control system in its entirety will be subsequently discussed.

Detailed Description Text (8):
The multivariable computer control system (FMC) is a future development which will

be compatible with the two previously mentioned systems, the FBC and the FPC, as a means of eliminating decision making by a human operator. It is anticipated that upon development of an automated inspection system capable of viewing a molded part and feeding back notations of defects or imperfections therein, the FMC may completely eliminate in-process human inputs. The FMC closes the control loop around the product. In absence of automated inspection, the results of human inspection may be reported to a computer. Using a multivariable control strategy, presently being developed, the computer may determine the necessary changes to the set points of the various control variables to produce a part with qualities conforming to the input specifications. The computer control system in its preferred form would interface directly with the injection molding machine control through the process control system FPC. The FMC would have the capacity to relate imperfections in a molded product to needed changes in the controllable process parameters. Calibrated voltages may be generated to direct changes in parameters and fed directly to the FPC which would incorporate the changes into the process.

Detailed Description Text (10):
Referring now to the drawings in general, and to FIG. 1 in particular, the FBC controls of an injection molding machine, indicated generally by reference numeral 2, adapted to be mated with the more advanced control systems FPC and FMC (not shown). Machine 2 includes a barrel 4 with a plasticating chamber 6 axially therein. Disposed within chamber 6 is plasticating screw 8 rotatably and slidably mounted therein. The screw 8 is connected to a shaft 10 coupled to a source of rotary motion 12 and basic control 13 therefore generally indicated as a block on the diagram but understood to be means such as an electric or hydraulic motor, well known in the art. Also connected to shaft 10 is means 14 also generally indicated in block form and understood to comprise conventional screw back pressure motor means and basic control 15 therefore.

Detailed Description Text (12):
Disposed in the forward end of barrel 4 is temperature sensing means such as temperature transducer 30, the sensing portion of which projects into chamber 6 generally in the nozzle area to accurately measure the temperature of the mass being plasticated within said chambers. Transducer 30 is also proximate nozzle 22 in the preferred embodiment so that the frictional effect upon the material flowing through nozzle 22 during the injection stroke is also sensed. In the preferred embodiment the temperature transducer 30 provides a calibrated voltage signal directly proportional to the melt temperature.

Detailed Description Text (13):
Also communicating with the melt chamber 6 is pressure transudcer 32 which is capable of supplying a calibrating voltage indicative of the pressure existing within the plasticated mass at chamber 6 during the injection cycle. Injection molding machine 2 is also equipped with a ram position transducer 34 capable of supplying a calibrated voltage indicative of the screw position. The output from position transducer 34 also includes a second calibrated voltage signal indicative of a velocity or speed of the screw, as shown in the preferred embodiment.

Detailed Description Text (14):
Conventional injection molding machines frequently used mechanical limit switches to sense clamp and injection positions as various points in the cycle. The FBC utilizes electrical position sensors capable of producing voltage indications of the various control functions at which they monitor. In such a manner the position of a switch or clamp may supply a voltage indicative of the position thereof so that this information may be directly fed back to the more advanced control systems subsequently discussed.

Detailed Description Text (15):
Likewise, in the elements in the FBC system for controlling the basic functions of injection molding, the hydraulic pressure relief valves are the electro-hydraulic type. Therefore, such machine parameters such as injection pressures both high and hold and back pressures as well as clamp pressures may be set by calibrated potentiometers which are an integral part of the basic pressure related valves control circuit. In adapting a conventional injection molding machine to the FBC type control system, the conventional manual flow control valves are replaced by

servo valves which are used in conjunction with variable displacement pumps occurring within the back pressure means 16 and screw speed means 14. This substitution provides pressures and speeds which are accurately commanded and known at all times due to the precise linearity between the command signal and function which are characteristics of these types of controls. As with the position set points the pressures and speeds may be modified electrically.

Detailed Description Text (16):
The specific control items above mentioned such as servo valves, electro-hydraulic pressure release valves and electrical position sensors are well known in the art and readily available from controls equipment suppliers. Such controls are adapted to the conventional injection molding machine such as is illustrated in FIG. 1 to adapt it to be compatible with the control systems subsequently described. These control elements are presently used with coordinating systems capable of generating calibrated electrical voltages to direct the function of these electric control elements such as the PM-1000 control available from the General Electric Company.

Detailed Description Text (20):
It will be appreciated in subsequent portions of the specification that the controls are represented in block (functional) form as the basic building elements familiar to controls engineers and that the specific control elements are available from any one of a number of controls suppliers given the described sequence and function. As subsequently presented, the control system FPC is illustrated as an electro-mechanical composite of functional sensors, actuators, comparators, etc. The illustrative system is interdependent upon calibrated voltages generated by various elements within the system. Certain process parameters are input to the control by means of "set points", as subsequently described. Within the context of the present application, the set point may include a potentiometer or variable voltage device included in a voltage responsive circuit, wherein the device provides a calibrated voltage responsive of the set point of the control knob, or the like. The presently disclosed system is adapted to cooperate with the General Electric Company PM-1000 basic injection molding machine process controller operating as an integral portion of the FBC.

Detailed Description Text (24):
In operation, the screw injection velocity is supplied to interrogator 43. When the velocity reaches a "threshhold" level, as set at 44 and compared at 45, an output signal is generated as indicated, to the FBC section 15 controlling the screw 6 injection stroke, and to the FPC, melt temperature control 50. To insure that the threshhold velocity is not sensed on the initial rise of velocity of the screw on the injection stroke, a delay may be set in through interrogator 43. As illustrated, until the screw passes a particular set point (well within the stable velocity range), circuit 43 is not activated to supply a signal to comparator 45.

Detailed Description Text (25):
The "zero" velocity section 46 supplies an output when the screw injection stroke is completed. Theoretically, when the screw ceases forward movement, or reaches zero velocity, the mold M is fully packed and material solidified and the injection stroke is completed. Practically speaking, forward velocity does not come to a definite halt. Rather, some nominal amount of movement continues, due to leakage of material, etc. Thus, a "zero" or nominal setting is set in at 48 to supply a nominal value to comparator 47. When the actual screw velocity drops to this low value, comparator 47 supplies an output signal. Preferably, the "zero" velocity signal is passed through a variable timer 49, which may provide a further preset delay, to any zero velocity signal. The zero velocity signal is supplied to the FBM (back pressure control 15) to switch off the hold pressure. The signal is also supplied to the shot volume control 60 to give a position indication of the completion of the injection stroke.

Detailed Description Text (26):
A primary function of the velocity range monitor 40 is to direct the shifting of the pressure produced by injecting screw 6 from the high injection pressures to holding pressure, sequentially, in the requisite time frame. In conventional approaches to molding it will be recognized that these various events of pressure shifting from injection to hold, then to cure pressure settings, were arrived at through trial and

error time settings with no feed back of the specific process events which were, in fact, occurring in the injection molding process. It is the function of the velocity range monitor 40 to recognize the occurrence of such events as "mold full", then direct the subsequent pressure shift to the holding pressure. The monitor then notes "mold seal" or solidification of the material at the nozzle 22, and directs the next desired pressure shift and subsequently directs the return of the ram and mixing screw to its proper return position.

Detailed Description Text (28):
FIG. 2a illustrates the pressure/position relationship of the injection stroke. The "mold full" event thus signals the appropriateness of the shift from the relatively high injection pressure to the more nominal holding pressure utilized during the solidification stage. It should be appreciated that the more quickly the "mold full" condition can be recognized, the more quickly and smoothly the shift from injection pressure to holding pressure may be effected. This prompt and smooth shift materially reduces or avoids the problem of flashing.

Detailed Description Text (31):
Melt Temperature Control--Achieving a desired melt temperature and maintaining that temperature within enclosed limits once it has been reached is an important aspect of injection molding control. The control diagrammed in FIG. 3 performs in accordance with the invention as subsequently described. The fast response of plastic temperature to a change in command as well as the uniformity of temperature distribution within the melt are essential characteristics of such a control system. To achieve these characteristics the invented control adopts a priority sequence whereby the conversion of the mechanical energy to heat within the melt is utilized as much as possible in preference to conductive heat from the barrel heaters. The control also attempts to maintain as nearly an adiabatic condition as practical within the barrel/melt chamber 6 by keeping the barrel zone heaters 24 at the selected melt temperatures. This approach minimizes heat flow from the heaters into the melt itself and thus minimizes temperature gradient in the transverse direction of the barrel.

Detailed Description Text (32):
The three process parameters which contribute toward the generation of melt temperature in the injection molding machine are: the barrel temperature, the back pressure on the plasticating screw, and the screw speed. For every material which is injection molded there are initial values of these three parameters, which, on the basis of past experience, are felt capable of producing an acceptable product. In order to adjust the process parameters, however, in the event that the molded part fails to come up to the required standards or the temperature strays from the preset value due to environmental changes, each of these parameters must be coordinately controlled so that the melt to be injected is restored to its proper temperature or adjusted to a different temperature felt to be more satisfactory. In order to effect this control of melt temperature each of the three parameters controlled by the melt temperature control 50 within the circuitry is adjustable by a nominal error setting, which for the purposes of this application will be designated a delta (.DELTA.) setting.

Detailed Description Text (33):
Referring now to FIG. 3, the melt temperature control 50 subsystem is shown in block diagram form. Primary input to the control 50 comes from the melt temperature transducer 30 which, in FIG. 1, is located in the nozzle area 22 of the melt chamber 6. A second input to the melt temperature control 50 is the melt temperature set point 52. This value is the selected temperature for the melt to be injected and is also the nominal setting for the barrel temperature of the injection molding machine. As illustrated in the diagram, this set point input is conveniently a potentiometer or variable resistance device within a voltage circuit such that a calibrated voltage is produced and which may be fed into the control 50 and utilized therein. The inputs from melt temperature transducer 30 and melt temperature set point 52 are supplied to amplifier means 53 capable of generating a voltage signal directly proportional to the difference between the two input temperatures. This error signal is supplied to further amplifier means 54 herein labeled Priority Sequence Circuit. The priority circuit 54 studies the error signal and generates the previously mentioned delta signal to be supplied back to one of three subcircuits

for the three previously mentioned parameters, which subcircuits effect the control and adjustment of the three previously mentioned parameters through the FBC and barrel temperature control 26 to establish the new melt temperature. Thus, the priority sequence circuit selectively activates: (1) amplifier means 57 to provide a control signal for the injection molding machine back pressure means 15; (2) amplifier 58 to supply a control signal to screw speed control means 13; or (3) amplifier means 59 to supply a control signal to the barrel heaters control 26. Screw back pressure set point 57a and screw speed set point 58a represent inputs of initial values of screw pressure and speed, anticipated to give a satisfactory melt temperature. A temperature stabilization circuit 55 is disposed between melt temperature transducer 30 and priority sequence 54. The function of this circuit 55 is to insure that control signals are not generated and supplied erroneously to the heater control 26 or back pressure control 15 or screw speed control 13 when the melt temperature is in a transient state. Stabilization circuit 55 disengages the function of the priority sequence circuit 54 at such times as when the melt temperature sensed by the transducer 30 is varying or changing. The melt temperature control 50 may be used individually to be directly coupled to the various related elements of the basic control system FBC. In the preferred embodiment illustrated, the melt temperature control 50 provides its signals to a portion of the overall FBC a portion of which is the previously mentioned coordinate control available from the General Electric Company, Salem, Va., as PM-1000. This control serves to collect several such control subsystem signals and supply a final control system signal to the basic control elements within the system FBC.

Detailed Description Text (34):
In operation, the melt temperature control circuit at 50 may respond either to direct input from a manual operator or from a sophisticated sensor system having the capability of determining an appropriate melt temperature. Assuming an actual melt temperature lower than a determined melt temperature, an operator or a related FPC or FMC control may initiate a signal to readjust the melt temperature set point 52. The device at 52 might be a manually set potentiometer or a servo control driven by an outside control as from the FMC. The new melt temperature set point is supplied directly to amplifier 59 and thus the barrel controls 26, to cause the barrel heaters 24 to go immediately to the new set point temperature. If the change between old and new melt set temperature points is quite small, the adjustment of barrel heat to the new set point may be sufficient to raise the melt temperature to the desired value. If the temperature difference is more significant, raising the barrel heat to set point may not result in sufficient heat to bring the plastic up to the desired temperature. When the melt temperature is stabilized and a difference or error signal exists between set point 52 temperature and melt temperature as taken by transducer 30, a control signal will be produced from amplifier 53 to raise the melt temperature toward the desired value. As previously mentioned whenever the error signal exists, a delta value is generated by the priority sequence circuit 54 to effect an increase in melt temperature. We have found a particular sequence of effecting the changes in the three parameters significantly more effective than other methods. According to the logic chosen for the priority sequence circuit 54, when a positive error exists between the melt temperature set point and the actual temperature, the screw speed will first be increased so as to decrease the error. The screw speed will be continually increased so long as an error exists, until the preset limit of screw speed is reached. This limit may be a process limitation imposed by a particular material or it may be an output limitation upon the injection molding machine itself such as upon the screw motor 12.

Detailed Description Text (41):
Shot Volume Control--Referring now to FIG. 4, the block diagram of the shot volume control subsystem 60 is illustrated. Initial values are set into the control to establish the nominal value of the screw back or recharge position. This value is set into the screw back positon set point 62 and may be a variable potentiometer or other device for supplying a calibrated voltage signal. Thus, upon completion of an injection molding cycle and when so cycled by the controller, as the screw 8 and chamber 6 fill, and the screw retracts back during the plasticating operation, it will so track until it reaches a position corresponding to the value set into the screw back position set point 62.

Detailed Description Text (42):

A desired final cushion size is established by setting a corresponding screw position into the control at final cushion size set point 64. This element is also a device capable of supplying a calibrated voltage signal. The input of this value establishes the desired forwardmost tracking position of the screw 8 during the injection stroke. A cushion is deliberately set in so that the screw does not bottom out against the nozzle area 22 on the injection stroke. This ensures that there will be adequate material available in the chamber to fill the mold prior to bottoming out. As the injection stroke is initiated, the position transducer 34 feeds information to the shot volume control 60, to differential amplifier 66. Amplifier 66 supplies an output indicative of the difference of cushion set point 64 and screw position 34 to a sample hold circuit 67. When zero velocity is detected at the end of the stroke by the velocity range monitor 40, the zero velocity signal from the velocity range monitor activates circuit 67 which samples the error in final screw position as determined by amplifier 66. This error is stored in memory means in circuit 67. This increment or decrement of error is then used to offset the screw back position set point 62 through amplifier 68 which supplies a new (corrected) screw back position to comparator 69. Thus, when screw 8 recharges, it tracks back until the position as signaled by transducer 34 matches the new recharge position as supplied by amplifier 68 and determined by comparator 69. Comparator 69 then signals the FBC that the screw 8 is ready for another shot. If screw 8 stops prior to desired final cushion set point because the mold then is full, the screw recharge position value will be readjusted. The control will reset so that the total shot size is lessened and the screw 8 returned to a position short of the originally set position. If the ram passes the indicated final cushion set point approaching a bottoming out, a positive error signal will be developed. Upon comparison will the actual final cushion set point and the desired final cushion set point, a delta signal is generated which will drive the screw recharge position in a direction to enlarge the shot size. As with the previous subsystem, the shot volume control 60 relies upon the velocity range monitor 40 control to determine the regions of the velocity curves (FIG. 2a) such that "zero" velocity and "mold full" positions are identified. The shot volume control may then make its observations at these particular process events and thus readjust and recalculate shot volume size accurately.

Detailed Description Text (45):
Pressure Monitoring System--Referring now to FIG. 5 a block diagram of the pressure monitoring system 70 is illustrated. Screw position transducer 34 provides an input of screw 6 position during the injection stroke. A designated position where sampling is to occur is input through set point 71. These inputs are supplied to a comparator 72 which outputs a signal to a sample and hold circuit 73. Circuit 73 is capable of sampling a pressure from transducer 32 and holding the value for later reference. At a preselected sample position, the pressure signal is released to differential amplifier 74 where it is compared with a preselected ideal pressure signal supplied from set point 75. Amplifier may supply various monitors and alarms as null meter 76 or bells or lights 77 and 73 which may signal an out of tolerance condition.

Detailed Description Text (46):
A correlation may be generally found between repetitively successful injection shots and the injection pressure required to fill the mold. The pressure monitor system automatically samples the pressure at a preselected position of the screw during injection stroke and compares it with a set point. If the difference between the set point and actual pressure exceeds a preselected range, an alarm means may be actuated. This may be in form of a bell, a light or both, singly or in conjunction with a direct feed back to the injection stroke controller. This will warn the controller (operator or automatic control) that conditions have changed as by different melt or mold temperature or possibly by obstructions in the path flow, to the extent that product qualities have been or will be affected. This range is preferably set by adjustable upper and lower limit potentiometers. These limits as well as the set point itself are typically dictated by experience. Parts with critical dimensional tolerances will require a relatively narrow range of allowable dynamic injection pressure. The point at which this pressure is sampled is adjustable to allow optimum correlation. To implement this feature a pressure transducer may be added to the injection hydraulic line and a positioned sensor such as a portion of the velocity range monitor control is utilized. In lieu of the

position transducer in the injection hydraulic line, a sensor 34 in the mold nozzle or portion of the flow path may be utilized, as illustrated.

CLAIMS:

1. A control for the temperature of plastic melt within an injection molding machine having a barrel, heating means for heating said barrel, a screw within said barrel, motor means for rotating the screw and means for applying pressure to said screw in a direction along its longitudinal axis whereby said screw acts as a piston comprising:

a. a first control means connected to said heating means for controlling the amount of heat supplied to said barrel by said heating means;

b. a second control means connected to said motor means for varying the rotational speed of said screw;

c. a third control means connected to said means for applying pressure to said screw for varying the amount of pressure applied to said screw; and

d. means interconnecting said first, second and third control means for rendering said control means selectively operable whereby the temperature of the plastic melt is maintained within predetermined limits.

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TITLE: Injection molding machine controls

Abstract Text (1):
Method for controlling the parameters of injection molding processes in a machine having a barrel with a plasticating chamber and a screw, rotatably and slidably disposed in said chamber, hopper means adjacent one end of said chamber communicating therewith and nozzle means disposed in the other end of said chamber communicating with a mold. Control of the injection molding process is achieved through an event recognition philosophy by sensing screw position, screw injection velocity, melt temperature, comparing the values at certain instances during the work cycle with known or desired values and using these values, changes of values and differences of values to monitor and initiate changes in the process parameters.

Brief Summary Text (2):
This invention relates to advanced control systems for injection molding such as supplied by the Farrel Company, Division of USM Corporation, Ansonia, Connecticut. These controls may be said to be extensions of conventional control system concepts. In this regard, conventionally, a number of direct process variables such as melt temperature and shot volume are adjusted indirectly by manipulating or adjusting the various direct machine controls such as position limit switches, speed regulators, and timing devices which may be directly mounted upon the machine to effect these variables. Other direct process variables such as shot holding time and in mold time are conventionally controlled by timer without being controlled positively in direct relation to specific events within the injection process. In the advanced control system subsequently described, conventional machine sensors and actuators affecting the various events in the total process have been repositioned, replaced and supplemented, and the machine controls have been sequentially readjusted and made interresponsive to provide an overall control of the injection molding procedure not previously available.

Brief Summary Text (3):
Among the overall objectives of the control system, the advance control system is to control certain key process variables individually, or directly, by individually sensing the process parameters and generating appropriate feed-back signals, and then using these signals to initiate or perform the specific control task for adjustment of the process. This, to a large extent, enables the usual machine process control decisions to be taken out of the hands of manual operators and provides a system which produces an acceptable product under semi-automated and varied operating conditions. The advanced control system contemplated herein may be broken down into several subsystems performing individual or localized process control functions; and among these are melt temperature control, shot volume control and various monitoring of "remote" control process variables.

Brief Summary Text (4):
The present invention relates in general to method for controlling the plasticating of polymeric materials in injection molding processes. More specifically, this invention relates to (1) control of the heat energy supplied to or generated within the plasticating apparatus for melting and plasticating the material; (2) control of the quantity of plastic material subsequently injected into a mold associated with the machine; (3) sequential and quantitive control of the various pressures exerted on the plastic material during the injection process; and (4) the flexibility to

provide coordinated adjustment of all of the above in response to product evaluation signals when direct input of these values is available.

Brief Summary Text (6):
It has been recognized that the plastic materials used in the injection molding processes today often require that the melt temperature be accurately controlled in order to carry out the injection molding process effectively. If the plastic material is either below or above the required temperatures the material may be incompletely plasticated or it may become discolored or otherwise deteriorated before or during injection molding procedure.

Brief Summary Text (8):
No controls existed prior to our invention to adjust and insure proper temperature of the melted, plasticated mass and to insure effective injection by a straightforward, sequential event-related approach. In many of the conventional plasticating and injection molding apparatus, the actual temperature of the mass injected is not measured or coordinatedly controlled during the continuing, repeated steps of the injection molding process. Much of the effort of control has been directed to a trial and error approach, finding acceptable values and then running a machine with these set values, with no provision for feed-back signals to check the set values. Specifically, these methods often only employ nominal temperature correction subsequent to the molding process consistent with visual observations of ineffective molding such as the aforementioned color changes or other material deterioration or the improper filling of a mold or other visible indications of unmixed or poorly mixed injection materials.

Brief Summary Text (10):
Resolution of the shot to shot problems involved in control of the melt temperature, however, do not individually provide the necessary speed of production in control over the production process to bring about the economy, efficiency and quality of production necessary for automated, high speed production. That aspect of the system should be coupled to responsive event control of shot volume and a continuing monitor/control of the injection stroke of the plasticating screw.

Brief Summary Text (11):
Conventional methods of controlling the volume of material injected into a mold by an injection molding machine include various timing means, position limit switches and position control switches influencing the screw backstroke to control the amount of polymeric material collected within the mixing chamber and then injected into the mold. It should be recognized that these conventional controls systems utilize input commands which are not indicative of the particular process parameters, or true events of the process. These conventional controls merely initiate step-by-step functions set by trial and error. By such conventional control systems the various process pressures and flow rates developed within the system are controlled by manual adjustment of relief valves and flow control valves, timing devices and the like.

Brief Summary Text (13):
While these conventional machines have been somewhat satisfactory for operation on relatively low volume basis, the control methods employed therein are totally unsatisfactory for a high-speed, fully automated molding machine. More particularly, the conventional control approaches would be totally unsatisfactory for a computer controlled machine including sensors capable of detecting the imperfections in its molding processes and products, and making appropriate corrections by adjustments in the particular process parameters which make up the molding process.

Brief Summary Text (14):
The present invention, then, relates to method for incrementally adjusting the temperature generated within one charge of the injection molding process, by coordinatedly controlling the speed of rotation of the screw, the back pressure of the screw and the barrel temperature of the plasticating chamber. In coordination with this, the invention includes method and apparatus for continually controlling the volume of the shot injected into the mold in the machine, and in addition the coordinated control of the sequential injection stroke of the screw according to the pressure and velocity patterns of the melt and screw during the injection process.

Drawing Description Text (2):
FIG. 1 is a diagrammatic presentation of the injection molding machine and control therefor for performing the method, in accordance with the invention;

Drawing Description Text (4):
FIG. 2a is a graphic representation of position, velocity and pressure pattern with respect to time during injection molding;

Detailed Description Text (2):
Method for controlling the parameters of injection molding processes in a machine having a barrel with a plasticating chamber and a screw, rotatably and slidably disposed in said chamber, hopper means adjacent one end of said chamber communicating therewith and nozzle means disposed in the other end of said chamber communicating with a mold. The general work cycle of such machine includes introducing polymeric material into said chamber through said hopper, rotating said screw to plasticate said material during which the screw is retracted in said chamber, and injecting the plasticated material into the mold through the nozzle by a forward or injection thrust of the screw. Control of the injection molding process is achieved through an event recognition philosophy by sensing screw position, screw injection velocity, melt temperature, comparing of values at certain instances during the work cycle with known or desired values and using these values, changes of values and differences of values to monitor and initiate changes in the process parameters.

Detailed Description Text (4):
The subsequent description relates to a new method for a family of control systems for injection molding machines. As subsequently disclosed, a family ultimately consists of three members. The basic control system (FBC), the process control system (FPC) and preferably the multivariable computer control system (FMC), all of which are closely related. By coupling the second member of the system to the first member and subsequently the third member to the group of the first two members, the resultant systems demonstrate increasing degrees of sophistication which exhibit an increasing independence from the human factor.

Detailed Description Text (5):
The basic control system which will subsequently be described, by and large follows a control strategy similar to today's conventional injection molding machine control systems. It will be pointed out however that this conventional strategy is uniquely implemented by virtue of the new understanding of injection molding process control and the particular combinations of sensors and systems employed to direct the various modes of the injection molding process. The basic control system is particularly adapted to perform with the process control (FPC).

Detailed Description Text (6):
The overall objective of the process control, (FPC), is to maintain the quality of the molded part independent of disturbances and variations in the injection molding environment once the primary operator has established the various control settings for the modes of injection molding. This objective is achieved by either introducing changes into the process variables which have deviated from the original set values or by warning the basic operator giving an indication of the process parameter which has deviated from the original setting, and which previously resulted in an acceptably molded part.

Detailed Description Text (7):
The process control (FPC) as subsequently described includes five subsystems which may be variously selected and combined to provide certain injection molding mode controls. Specific description of the subsystems and their interrelation with each other and the process control system in its entirety will be subsequently discussed.

Detailed Description Text (8):
The multivariable computer control system (FMC) is a future development which will be compatible with the two previously mentioned systems, the FBC and the FPC, as a means of eliminating decision making by a human operator. It is anticipated that

upon development of an automated inspection system capable of viewing a molded part and feeding back notations of defects or imperfections therein, the FMC may completely eliminate in-process human inputs. The FMC closes the control loop around the product. In absence of automated inspection, the results of human inspection may be reported to a computer. Using a multivariable control strategy, presently being developed, the computer may determine the necessary changes to the set points of the various control variables to produce a part with qualities conforming to the input specifications. The computer control system in its preferred form would interface directly with the injection molding machine control through the process control system FPC. The FMC would have the capacity to relate imperfections in a molded product to needed changes in the controllable process parameters. Calibrated voltages may be generated to direct changes in parameters and fed directly to the FPC which would incorporate the changes into the process.

Detailed Description Text (10):
Referring now to the drawings in general, and to FIG. 1 in particular, the FBC controls an injection molding machine, indicated generally by reference numeral 2, adapted to be mated with the more advanced control systems FPC and FMC (not shown). Machine 2 includes a barrel 4 with a plasticating chamber 6 axially therein. Disposed within chamber 6 is plasticating screw 8 rotatably and slidably mounted therein. The screw 8 is connected to a shaft 10 coupled to a source of rotary motion 12 and basic control 13 generally indicated as a block on the diagram but understood to be means such as an electric or hydraulic motor, well known in the art. Also connected to shaft 10 is means 14 also generally indicated in block form and understood to comprise conventional screw back pressure motor means and basic control 15 therefore.

Detailed Description Text (12):
Disposed in the forward end of barrel 4 is temperature sensing means such as temperature transducer 30, the sensing portion of which projects into chamber 6 generally in the nozzle area to accurately measure the temperature of the mass being plasticated within said chambers. Transducer 30 is also proximate nozzle 22 in the preferred embodiment so that the frictional effect upon the material flowing through nozzle 22 during the injection stroke is also sensed. In the preferred embodiment the temperature transducer 30 provides a calibrated voltage signal directly proportional to the melt temperature.

Detailed Description Text (13):
Also communicating with the melt chamber 6 is pressure transducer 32 which is capable of supplying a calibrating voltage indicative of the pressure existing within the plasticated mass at chamber 6 during the injection cycle. Injection molding machine 2 is also equipped with a ram position transducer 34 capable of supplying a calibrated voltage indicative of the screw position. The output from position transducer 34 also includes a second calibrated voltage signal indicative of a velocity or speed of the screw, as shown in the preferred embodiment.

Detailed Description Text (14):
Conventional injection molding machines frequently used mechanical limit switches to sense clamp and injection positions as various points in the cycle. The FBC utilizes electrical position sensors capable of producing voltage indications of the various control functions at which they monitor. In such a manner the position of a switch or clamp may supply a voltage indicative of the position thereof so that this information may be directly fed back to the more advanced control systems subsequently discussed.

Detailed Description Text (15):
Likewise, in the elements in the FBC system for controlling the basic functions of injection molding, the hydraulic pressure relief valves are the electro-hydraulic type. Therefore, such machine parameters such as injection pressures, both high and hold, and back pressures as well as clamp pressures may be set by calibrated potentiometers which are an integral part of the basic pressure related valves control circuit. In adapting a conventional injection molding machine to the FBC type control system, the conventional manual flow control valves are replaced by servo valves which are used in conjunction with variable displacement pumps occurring within the back pressure means 16 and screw speed means 14. This

substitution provides pressures and speeds which are accurately commanded and known at all times due to the precise linearity between the command signal and function which are characteristics of these types of controls. As with the position set points the pressures and speeds may be modified electrically.

Detailed Description Text (16):
The specific control items above mentioned such as servo valves, electro-hydraulic pressure release valves and electrical position sensors are well known in the art and readily available from controls equipment suppliers. Such controls are adapted to the conventional injection molding machine such as is illustrated in FIG. 1 to adapt it to be compatible with the control systems subsequently described. These control elements are presently used with coordinating systems capable of generating calibrated electrical voltages to direct the function of these electric control elements such as the PM-1000 control available from the General Electric Company.

Detailed Description Text (20):
It will be appreciated in subsequent portions of the specification that the controls are represented in block (functional) form as the basic building elements familiar to controls engineers and that the specific control elements are available from any one of a number of controls suppliers given the described sequence and function. As subsequently presented, the control system FPC is illustrated as an electro-mechanical composite of functional sensors, actuators, comparators, etc. The illustrative system is interdependent upon calibrated voltages generated by various elements within the system. Certain process parameters are input to the control by means of "set points", as subsequently described. Within the context of the present application, the set point may include a potentiometer or variable voltage device included in a voltage responsive circuit, wherein the device provides a calibrated voltage responsive of the set point of the control knob, or the like. The presently disclosed system is adapted to cooperate with the General Electric Company PM-1000 basic injection molding machine process controller operating as an integral portion of the FBC.

Detailed Description Text (24):
In operation, the screw injection velocity is supplied to interrogator 43. When the velocity reaches a "threshhold" level, as set at 44 and compared at 45, an output signal is generated as indicated, to the FBC section 15 controlling the screw 6 injection stroke, and to the FPC, melt temperature control 50. To insure that the threshhold velocity is not sensed on the initial rise of velocity of the screw on the injection stroke, a delay may be set in through interrogator 43. As illustrated, until the screw passes a particular set point (well within the stable velocity range), circuit 43 is not activated to supply a signal to comparator 45.

Detailed Description Text (25):
The "zero" velocity section 46 supplies an output when the screw injection stroke is completed. Theoretically, when the screw ceases forward movement, or reaches zero velocity, the mold M is fully packed and material solidified and the injection stroke is completed. Practically speaking, forward velocity does not come to a definite halt. Rather, some nominal amount of movement continues, due to leakage of material, etc. Thus, a "zero" or nominal setting is set in at 48 to supply a nominal value to comparator 47. When the actual screw velocity drops to this low value, comparator 47 supplies an output signal. Preferably, the "zero" velocity signal is passed through a variable timer 49, which may provide a further preset delay, to any zero velocity signal. The zero velocity signal is supplied to the FBM (back pressure control 15) to switch off the hold pressure. The signal is also supplied to the shot volume control 60 to give a position indication of the completion of the injection stroke.

Detailed Description Text (26):
A primary function of the velocity range monitor 40 is to direct the shifting of the pressure produced by injecting screw 6 from the high injection pressures to holding pressure, sequentially, in the requisite time frame. In conventional approaches to molding it will be recognized that these various events of pressure shifting from injection to hold, then to cure pressure settings, were arrived at through trial and error time settings with no feed back of the specific process events which were, in fact, occurring in the injection molding process. It is the function of the velocity

range monitor 40 to recognize the occurrence of such events as "mold full", then direct the subsequent pressure shift to the holding pressure. The monitor then notes "mold seal" or solidification of the material at the nozzle 22, and directs the next desired pressure shift and subsequently directs the return of the ram and mixing screw to its proper return position.

Detailed Description Text (28):
FIG. 2a illustrates the pressure/position relationship of the injection stroke. The "mold full" event thus signals the appropriateness of the shift from the relatively high injection pressure to the more nominal holding pressure utilized during the solidification stage. It should be appreciated that the more quickly the "mold full" condition can be recognized, the more quickly and smoothly the shift from injection pressure to holding pressure may be effected. This prompt and smooth shift materially reduces or avoids the problem of flashing.

Detailed Description Text (31):
Melt Temperature Control - Achieving a desired melt temperature and maintaining that temperature within enclosed limits once it has been reached is an important aspect of injection molding control. The control diagrammed in FIG. 3 performs in accordance with the invention as subsequently described. The fast response of plastic temperature to a change in command as well as the uniformity of temperature distribution within the melt are essential characteristics of such a control system. To achieve these characteristics the invented control adopts a priority sequence whereby the conversion of the mechanical energy to heat within the melt is utilized as much as possible in preference to conductive heat from the barrel heaters 24. The control also attempts to maintain as nearly an adiabatic condition as practical within the barrel/melt chamber 6 by keeping the barrel zone heaters 24 at the selected melt temperatures. This approach minimizes heat flow from the heaters into the melt itself and thus minimizes temperature gradient in the transverse direction of the barrel.

Detailed Description Text (32):
The three process parameters which contribute toward the generation of melt temperature in the injection molding machine are: the barrel temperature, the back pressure on the plasticating screw, and the screw speed. For every material which is injection molded there are initial values of these three parameters, which, on the basis of past experience, are felt capable of producing an acceptable product. In order to adjust the process parameters however, in the event that the molded part fails to come up to the required standards or the temperature strays from the preset value due to environmental changes, each of these parameters must be coordinately controlled so that the melt to be injected is restored to its proper temperature or adjusted to a different temperature felt to be more satisfactory. In order to effect this control of melt temperature each of the three parameters controlled by the melt temperature control 50 within the circuitry is adjusted by a nominal error setting, which for the purposes of this application will be designated a delta (.DELTA.) setting.

Detailed Description Text (33):
Referring now to FIG. 3, the melt temperature control 50 subsystem is shown in block diagram form. Primary input to the control 50 comes from the melt temperature transducer 30 which, in FIG. 1, is located in the nozzle area 22 of the melt chamber 6. A second input to the melt temperature control 50 is the melt temperature set point 52. This value is the selected temperature for the melt to be injected and is also the nominal setting for the barrel temperature of the injection molding machine. As illustrated in the diagram, this set point input is conveniently a potentiometer or variable resistance device within a voltage circuit such that a calibrated voltage is produced and which may be fed into the control 50 and utilized therein. The inputs from melt temperature transducer 30 and melt temperature set point 52 are supplied to amplifier means 53 capable of generating a voltage signal directly proportional to the difference between the two input temperatures. This error signal is supplied to further amplifier means 54 herein labeled Priority Sequence Circuit. The priority circuit 54 studies the error signal and generates the previously mentioned delta signal to be supplied back to one of three subcircuits for the three previously mentioned parameters, which subcircuits effect the control and adjustment of the three previously mentioned parameters through the FBC and

barrel temperature control 26 to establish the new melt temperature. Thus, the priority sequence circuit selectively activates: (1) amplifier means 57 to provide a control signal for the injection molding machine back pressure means 15; (2) amplifier 58 to supply a control signal to screw speed control means 13; or (3) amplifier means 59 to supply a control signal to the barrel heaters control 26. Screw back pressure set point 57a and screw speed set point 58a represent inputs of initial values of screw pressure and speed, anticipated to give a satisfactory melt temperature. A temperature stabilization circuit 55 is disposed between melt temperature transducer 30 and priority sequence 54. The function of this circuit 55 is to insure that control signals are not generated and supplied erroneously to the heater control 26 or back pressure control 15 or screw speed control 13 when the melt temperature is in a transient state. Stabilization circuit 55 disengages the function of the priority sequence circuit 54 at such times as when the melt temperature sensed by the transducer 30 is varying or changing. The melt temperature control 50 may be used individually to be directly coupled to the various related elements of the basic control system FBC. In the preferred embodiment illustrated, the melt temperature control 50 provides its signals to a portion of the overall FBC a portion of which is the previously mentioned coordinate control available from the General Electric Company, Salem, Virginia, as PM-1000. This control serves to collect several such control subsystem signals and supply a final control system signal to the basic control elements within the system FBC.

Detailed Description Text (34):
In operation, the melt temperature control circuit at 50 may respond either to direct input from a manual operator or from a sophisticated sensor system having the capability of determining an appropriate melt temperature. Assuming an actual melt temperature lower than a determined melt temperature, an operator or a related FPC or FMC control may initiate a signal to readjust the melt temperature set point 52. The device at 52 might be a manually set potentiometer or a servo control driven by an outside control as from the FMC. The new melt temperature set point is supplied directly to amplifier 59 and thus the barrel controls 26, to cause the barrel heaters 24 to go immediately to the new set point temperature. If the change between old and new melt set temperature points is quite small, the adjustment of barrel heat to the new set point may be sufficient to raise the melt temperature to the desired value. If the temperature difference is more significant, raising the barrel heat to set point may not result in sufficient heat to bring the plastic up to the desired temperature. When the melt temperature is stabilized and a difference or error signal exists between set point 52 temperature and melt temperature as taken by transducer 30, a control signal will be produced from amplifier 53 to raise the melt temperature toward the desired value. As previously mentioned whenever the error signal exists, a delta value is generated by the priority sequence circuit 54 to effect an increase in melt temperature. We have found a particular sequence of effecting the changes in the three parameters significantly more effective than other methods. According to the logic chosen for the priority sequence circuit 54, when a positive error exists between the melt temperature set point and the actual temperature, the screw speed will first be increased so as to decrease the error. The screw speed will be continually increased so long as an error exists, until the preset limit of screw speed is reached. This limit may be a process limitation imposed by a particular material or it may be an output limitation upon the injection molding machine itself such as upon the screw motor 12.

Detailed Description Text (41):
Shot Volume Control - Referring now to FIG. 4, the block diagram of the shot volume control subsystem 60 is illustrated. Initial values are set into the control to establish the nominal value of the screw back or recharge position. This value is set into the screw back position set point 62 and may be a variable potentiometer or other device for supplying a calibrated voltage signal. Thus, upon completion of an injection molding cycle and when so cycled by the controller, as the screw 8 and chamber 6 fill, and the screw retracts back during the plasticating operation, it will so track until it reaches a position corresponding to the value set into the screw back position set point 62.

Detailed Description Text (42):
A desired final cushion size is established by setting a corresponding screw position into the control at final cushion size set point 64. This element is also a

device capable of supplying a calibrated voltage signal. The input of this value establishes the desired forwardmost tracking position of the screw 8 during the injection stroke. A cushion is deliberately set in so that the screw does not bottom out against the nozzle area 22 on the injection stroke. This ensures that there will be adequate material available in the chamber to fill the mold prior to bottoming out. As the injection stroke is initiated, the position transducer 34 feeds information to the shot volume control 60, to differential amplifier 66. Amplifier 66 supplies an output indicative of the difference of cushion set point 64 and screw position 34 to a sample hold circuit 67. When zero velocity is detected at the end of the stroke by the velocity range monitor 40, the zero velocity signal from the velocity range monitor activates circuit 67 which samples the error in final screw position as determined by amplifier 66. This error is stored in memory means in circuit 67. This increment or decrement of error is then used to offset the screw back position set point 62 through amplifier 68 which supplies a new (corrected) screw back position to comparator 69. Thus, when screw 8 recharges, it tracks back until the position as signaled by transducer 34 matches the new recharge position as supplied by amplifier 68 and determined by comparator 69. Comparator 69 then signals the FBC that the screw 8 is ready for another shot. If screw 8 stops prior to desired final cushion set point because the mold then is full, the screw recharge position value will be readjusted. The control will reset so that the total shot size is lessened and the screw 8 returned to a position short of the originally set position. If the ram passes the indicated final cushion set point approaching a bottoming out, a positive error signal will be developed. Upon comparison with the actual final cushion set point and the desired final cushion set point, a delta signal is generated which will drive the screw recharge position in a direction to enlarge the shot size. As with the previous subsystem, the shot volume control 60 relies upon the velocity range monitor 40 control to determine the regions of the velocity curves (FIG. 2a) such that "zero" velocity and "mold full" positions are identified. The shot volume control may then make its observations at these particular process events and thus readjust and recalculate shot volume size accurately.

Detailed Description Text (45):
Pressure Monitoring System - Referring now to FIG. 5 a block diagram of the pressure monitoring system 70 is illustrated. Screw position transducer 34 provides an input of screw 6 position during the injection stroke. A designated position where sampling is to occur is input through set point 71. These inputs are supplied to a comparator 72 which outputs a signal to a sample and hold circuit 73. Circuit 73 is capable of sampling a pressure from transducer 32 and holding the value for later reference. At a preselected sample position, the pressure signal is released to differential amplifier 74 where it is compared with a preselected ideal pressure signal supplied from set point 75. Amplifier may supply various monitors and alarms as null meter 76 or bells or lights 77 and 73 which may signal an out of tolerance condition.

Detailed Description Text (46):
A correlation may be generally found between repetitively successful injection shots and the injection pressure required to fill the mold. The pressure monitor system automatically samples the pressure at a preselected position of the screw during injection stroke and compares it with a set point. If the difference between the set point and actual pressure exceeds a preselected range, an alarm means may be actuated. This may be in form of a bell, a light or both, singly or in conjunction with a direct feed back to the injection stroke controller. This will warn the controller (operator or automatic control) that conditions have changed as by different melt or mold temperature or possibly by obstructions in the path of flow, to the extent that product qualities have been or will be affected. This range is preferably set by adjustable upper and lower limit potentiometers. These limits as well as the set point itself are typically dictated by experience. Parts with critical dimensional tolerances will require a relatively narrow range of allowable dynamic injection pressure. The point at which this pressure is sampled is adjustable to allow optimum correlation. To implement this feature a pressure transducer may be added to the injection hydraulic line and a positioned sensor such as a portion of the velocity range monitor control is utilized. In lieu of the position transducer in the injection hydraulic line, a sensor 34 in the mold nozzle or portion of the flow path may be utilized, as illustrated.

CLAIMS:

1. A method for controlling the parameters of an injection molding process, said molding process including: feeding material into a plasticating chamber, applying, by the use of heaters, a predetermined amount of heat to the chamber which is calculated to cause the plasticated material to reach a predetermined standard temperature, rotating a plasticating screw located in the chamber at a predetermined speed to plasticate the material, slidably retracting the screw during plastication, under a predetermined back pressure, to a charged position to collect a predetermined quantity of plasticated material ahead of the screw, and injecting the material into a mold by a forward sliding thrust of the screw, said control method comprising:

A. detecting the temperature of the plasticated material;

B. comparing the temperature of the plasticated material with the predetermined standard temperature; and

C. adjusting the supply of heat energy to the plasticating chamber to compensate for any difference in the temperature of the plasticated material and the standard temperature, for subsequent injection cycles by selectively adjusting rotational screw speed, back pressure, and the heat applied by the chamber heaters according to a priority sequence which maximizes the input of mechanical energy.

2. A method for controlling the parameters of an injection molding process as described in claim 1 wherein the priority sequence utilized for increasing the temperature of the plasticated material comprises:

A. first, increasing the rotational speed of the screw to obtain, maximum compensation therefrom;

B. second, increasing the back pressure on the screw to obtain maximum compensation therefrom; and

C. third, increasing the heat applied by the chamber heaters until full compensation is obtained.

3. A method for controlling the parameters of an injection molding process as described in claim 1 wherein the priority sequence utilized to decrease the temperature of the plasticated material comprises:

A. first, decreasing the heat applied by the chamber heaters to obtain, maximum compensation therefrom;

B. second, decreasing the back pressure on the screw to obtain maximum compensation therefrom; and

C. third, decreasing the rotational speed of the screw until full compensation is obtained.

US-CL-CURRENT: 425/144; 374/142, 425/145, 425/149

ABSTRACT:

Method and apparatus for controlling the parameters of injection molding processes in a machine having a barrel with a plasticating chamber and a screw, rotatably and slidably disposed in said chamber, hopper means adjacent one end of said chamber communicating therewith and nozzle means disposed in the other end of said chamber communicating with a mold. Control of the injection molding process is achieved through an event recognition philosophy by sensing screw position, screw injection velocity, melt temperature, comparing the values at certain instances during the work cycle with known or desired values and using these values, changes of values and differences of values to monitor and initiate changes in the process parameters.

23 Claims, 7 Drawing figures
Exemplary Claim Number: 1,17
Number of Drawing Sheets: 5

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Term	Documents
AUTOMATED	174060
AUTOMATEDS	0
CONTROL	4576922
CONTROLS	980917
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Previous Page   Next Page